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After reading this chapter you should know the answers to these questions:

- What are the key components of Medical Image interpretation?
- What are the roles of the Radiology Information System (RIS), Picture Archiving and Communication System (PACS), Computer-Aided Diagnosis (CAD), and Advanced Visualization Systems in a typical medical imaging department?
- How does the DICOM standard differ from HL-7 in its information model structure?

20.1 Introduction

In Chap. 9, we introduce the concept of **digital images** as a fundamental data type that, because of its ubiquity, must be considered in many applications. We define biomedical **imaging informatics** as the study of methods for generating,

manipulating, managing, extracting, and representing imaging information, plus integrating images in many biomedical applications.

In this chapter we continue the study of imaging informatics, begun in Chap. 9, by describing many of the methods for generating and manipulating images, particularly as applied to the brain, and discuss the relationship of these methods to structural informatics. We emphasize methods for managing and integrating images, focusing on how images are acquired from imaging equipment, stored, transmitted, and presented for interpretation. We also focus on how these processes and the image information are integrated with other clinical information and used in the health care enterprise, so as to have an optimal impact on patient care.

We discuss these issues in the context of Radiology, since imaging is the primary focus of that field.¹ Yet imaging is an important part of many other fields as well, including Pathology, Hematology, Dermatology, Ophthalmology, Gastroenterology, Cardiology, Surgery (for minimally invasive procedures especially) and

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¹ The name Radiology is itself a misnomer, since the field is involved in using ultrasound, magnetic resonance, optical, thermal, and other non-radiation imaging modalities when appropriate. Radiology departments in some institutions are thus referred to alternatively as Departments of Medical Imaging or Diagnostic Imaging.

Obstetrics, which often do their own imaging procedures; most other fields that use imaging rely on Radiology and Pathology for their imaging needs.

The distribution of imaging responsibility has given rise to the need of many departments to address issues of image acquisition, storage, transmission, and interpretation. As these modalities have gradually become largely digital in format, the development of electronic systems to support these tasks has been needed.

We begin by describing some of the roles of imaging across all of biomedicine, then concentrate on their management and integration in radiology systems, bringing in illustrative examples from other disciplines where appropriate. Many Radiology departments are becoming highly distributed enterprises, with acquisition sites in intensive care unit areas, regular patient floors, emergency departments, vascular services, screening centers, ambulatory clinics, and in affiliated community-based practice settings. Interpretation of images may be in those locations when dedicated onsite radiologists are needed. Increasingly, however, due to high-speed network availability, interpretation can be done at sites far from acquisition, either in a central location or in widely distributed locations according to the different methods of organization. This variation is possible because image acquisition and interpretation can be effectively decoupled. Independent imaging centers in a community face some of the same issues and opportunities, although to a lesser degree, so we focus primarily on the distributed medical center-based Radiology department in this chapter.

20.2 Basic Concepts and Issues

20.2.1 Roles for Imaging in Biomedicine

Imaging is a central part of the health care process for diagnosis, treatment planning, image-guided treatment, assessment of response to treatment, and estimation of prognosis. In addition, it plays important roles in medical communication and education, as well as in research.

20.2.1.1 Detection and Diagnosis

The primary uses of images are for the detection of medical abnormalities and for diagnostic purposes. Detection focuses on identifying the presence of an abnormality, but in the case in which the findings are not sufficiently specific to be characteristic of a particular disease, other information is required for actual diagnosis. This is the case, for example, with mammograms, which are often used for screening for breast cancer; once a suspicious abnormality is detected, a biopsy procedure is usually required for diagnosis. In other circumstances, the image finding is adequate to diagnose the abnormality, for example, the finding of focal stenosis or obstruction of a coronary artery during angiography is diagnostic in itself, and some tumors, congenital abnormalities, or other diseases have highly characteristic appearances. Most often there is a continuum between detection and diagnosis, with a test able not only to detect but also to narrow the range of possibilities, known as the **differential diagnosis** (see Chap. 2).

Diagnosis and detection can be done with a wide variety of imaging procedures. Images produced by visible light, as in ophthalmology, for example, can be used for retinal photography; in dermatology, to view skin lesions; and in pathology, for gross specimen viewing and for light microscopy. The visible-light spectrum is also responsible for producing images seen endoscopically, rendered typically as video images or sequences. Sound energy, in the form of echoes from internal structures, is used to form images in ultrasound, a modality used primarily in cardiac, abdominal, pelvic, breast, and obstetrical imaging, as well as in imaging of small parts, such as the thyroid and testes. In addition, **Doppler shifts** of sound frequency are used to evaluate blood flow in many organs and in major vessels. X-ray energy produces radiographic and **computed-tomography** (CT) images of most parts of the body: The differential absorption of X-rays by various tissues produces the varying densities that enable radiographic images to portray normal and abnormal structures. Isotope emissions of radioactive particles are used to produce nuclear-medicine images, which result from

the differential concentration of radioactively tagged molecules in various tissues. **Magnetic-resonance imaging (MRI)** depicts energy fluctuations of certain atomic nuclei—primarily of hydrogen—when they are aligned in a magnetic field and then perturbed by a radiofrequency pulse. Parameters such as proton density, the rate at which the nuclei return to alignment, the rate of loss of phase coherence after the pulse, diffusion of water, and even the concentration of certain chemicals can be measured. These quantities differ in various tissues under normal conditions, with more variations due to disease, thus enabling MRI to distinguish among them. Figure 20.1 shows some example images.

20.2.1.2 Assessment and Planning

In addition to being used for detection and diagnosis, imaging is often used to assess a patient's health status in terms of progression of a disease process (such as determination of tumor stage), response to treatment, and estimation of prognosis. We can analyze cardiac status by assessing the heart's size and motion echocardiographically. Similarly, we can use ultrasound to assess fetal size and growth, as well as development. Computed tomography is used frequently to determine approaches for surgery or for radiation therapy. In the latter case, precise calculations of radiation-beam configuration can be optimized to maximize dose to the tumor while minimizing absorption of radiation by surrounding tissues. This calculation is often performed by simulating multiple radiation-beam configurations and iterating to a best treatment plan. For surgical planning, three-dimensional volumes of CT or MRI data can be constructed and presented for viewing from different perspectives to facilitate determination of the most appropriate surgical approach.

20.2.1.3 Image-Guided Procedures

Images can provide real-time guidance when virtual-reality methods are used to superimpose a surgeon's visual perspective on the appropriate image view in the projection that demonstrates the abnormality. With endoscopic and minimally invasive surgery, this kind of imaging can provide

a localizing context for visualizing and orienting the endoscopic findings, and can enable monitoring of results of interventions such as focused ultrasound, cryosurgery, or thermal ablation. It is also possible to use intra-operative imaging to update the position and appearance of pre-operative imaging used for procedural planning. Figure 20.2 shows an example of a CT-guided biopsy of a lesion in the neck. High quality imaging allows precise targeting of small targets even near important structures like the carotid artery.

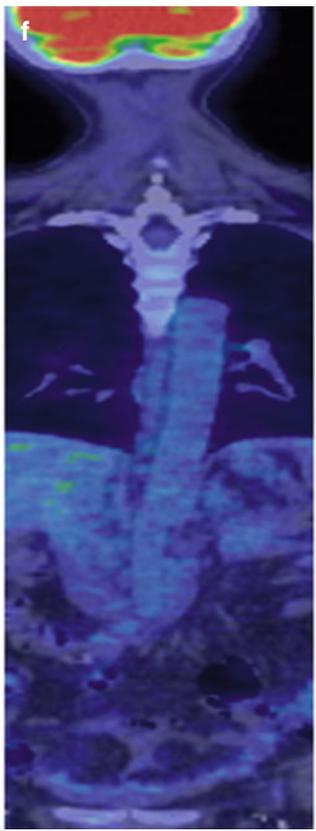
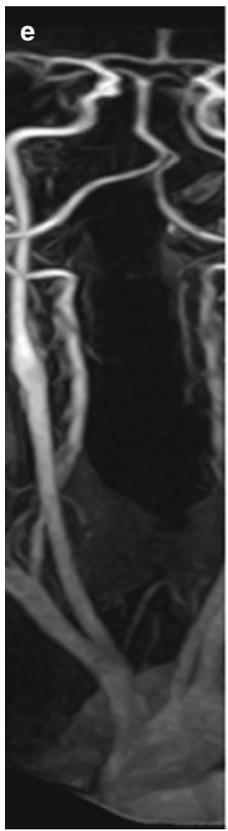
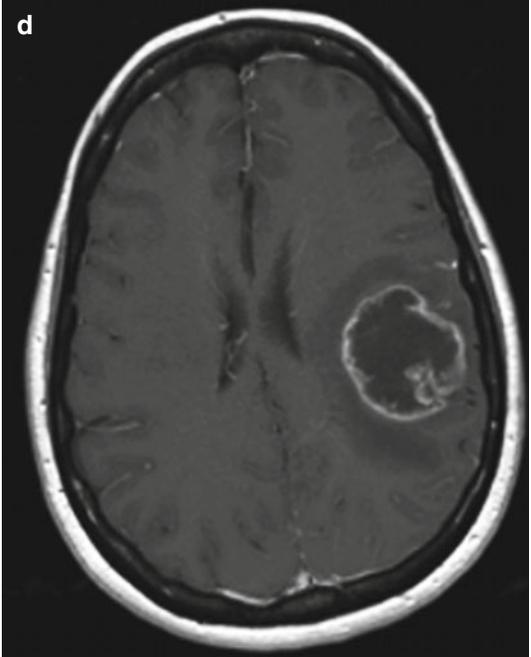
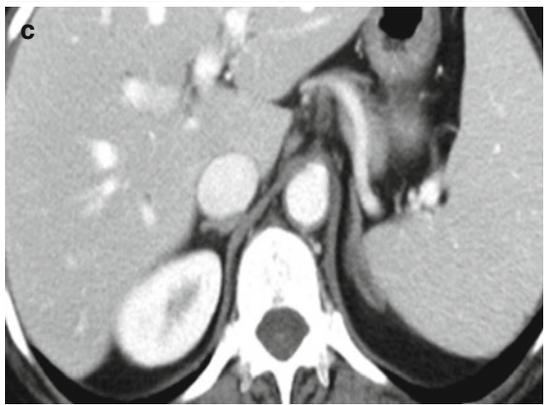
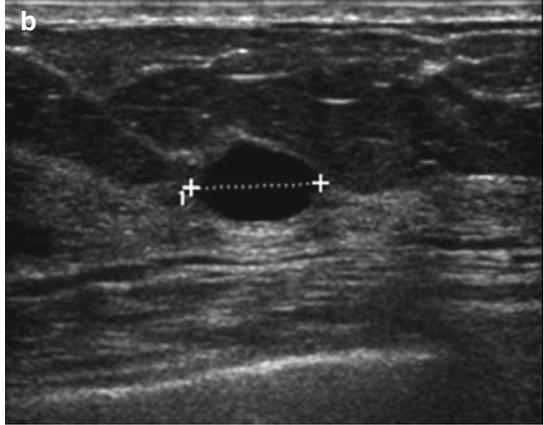
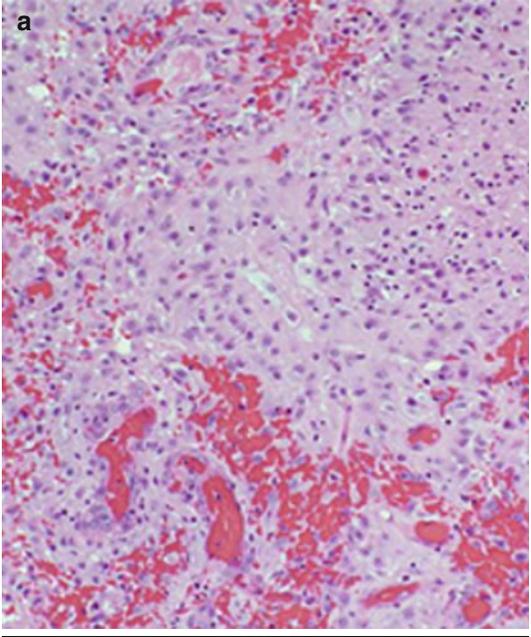
Such minimally invasive surgery can be conducted at a distance (see Chap. 18), although it is practical to do so only in limited settings. Because the abnormality is viewed through a video monitor that displays the endoscopic field, the view can be physically remote, a technique called **telepresence**. Similarly, the manipulation of the endoscope itself can be controlled by a robotic device that reproduces the hand movements of a remote operator, and can provide **haptic feedback** reproducing the sensations of tissue textures, margins, and resistance.

20.2.1.4 Communication

Medical decision-making, including diagnosis and treatment planning, is often aided by allowing clinicians to visualize images concurrently with textual reports and discussions of interpretations. Thus, we consider imaging to be an important adjunct to communication and images to be a desirable component of a multimedia electronic medical record. Because medical imaging is an essential element of the practice of medicine, support for transmission and remote image viewing is also a critical component of telemedicine (Chap. 18). Medical images can also be helpful in doctor-patient communication, to enable the provider to illustrate an abnormality or explain a surgical procedure to a patient (Chap. 17).

20.2.1.5 Education and Training

Images (2D or static, 3D, 4D (e.g., 3D CT or ultrasound through time), and video) are an essential part of medical education and training because so much of medical diagnosis and treatment depends on imaging and on the skills



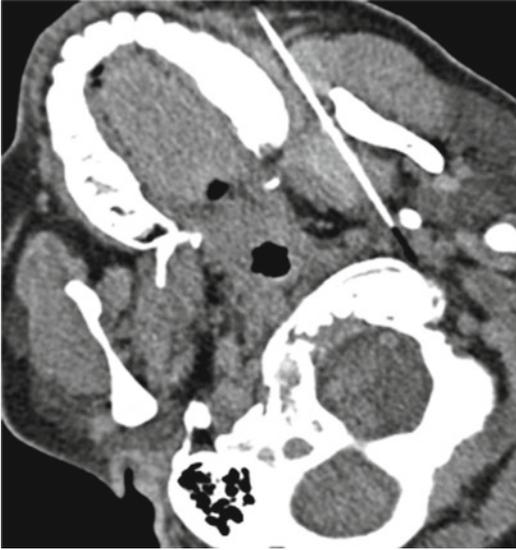


Fig. 20.2 An example of a CT-guided biopsy of a lesion in the neck. High quality imaging allows precise targeting of small targets even near important structures like the carotid artery

needed to interpret such images (see Chap. 22). Case libraries, tutorials, atlases, three-dimensional models, quiz libraries, and other resources using images can provide this kind of educational support.

Taking a history, performing a physical examination, and conducting medical procedures also demand appropriate visualization and observation skills. Training in these skills can be augmented by viewing images and video sequences, as well as through practice in simulated situations. An example of the latter is an approach to training individuals in endoscopy techniques by using a mannequin and video images in conjunction with tactile and visual feedback that correlate with the manipulations being carried out.

As noted in the previous section, patients increasingly expect to understand more about their disease, and patient communications can be more effective by including relevant images. Imaging also has a consumer/patient education benefit, since access to appropriate images can be

included along with the provision of instructions and educational materials to patients—about their diseases, about procedures to be carried out, about follow-up care, and about healthy lifestyles.

20.2.1.6 Research

Imaging is, of course, also intimately involved in many aspects of research. An example is structural modeling of DNA and proteins, including their 3D and 4D configurations (see Chap. 24). Another is the images obtained in molecular or cellular biology to follow the distributions of fluorescent or radioactively tagged molecules. The study of **morphometrics**, which is literally the measurement of shape, depends on the use of imaging methods. Figure 20.3 shows an example of a detailed segmentation of the brain into various anatomic structures by the Free Surfer package.² It uses a combination of image intensities and expected shapes for the brain and substructures to produce its output. **Functional mapping**—for example, of the human brain—relates specific sites on images to particular functions. While such quantitative imaging efforts often begin in the laboratory, translation of such quantitative methods is increasingly important to the practice of medicine. Figure 20.4 provides an example of functional mapping of a patient with a brain tumor, where functional mapping is used to identify critical structures, and thus to guide surgical therapy.

20.2.1.7 The Radiologic Process and Its Interactions

As noted in the introduction, we concentrate in this chapter on the subset of imaging that falls under the purview of **Radiology**. Radiology departments are engaged in all aspects of the health care process, from detection and diagnosis to treatment, follow-up and prognosis assessment, and they illustrate well the many issues involved in acquiring and managing images, interpreting them, and communicating those interpretations.

²<http://surfer.nmr.mgh.harvard.edu/> (Accessed 1/27/2013)

Fig. 20.1 Medical imaging leverages a variety of types of images to measure, diagnose and store information about a patient. Some examples are (a) Dermatopathology, (b) Ultrasound (US), (c) Computed Tomography (CT),

(d) Magnetic Resonance Imaging (MRI), (e) magnetic resonance angiogram, (f) fused PET-CT image, and (g) photographic image of the eye

Space does not permit us to discuss the other disciplines that utilize imaging, but the processes involved and issues faced, which we discuss in the context of radiology, pertain to the other disciplines also. Additional examples are also provided in Chap. 9. Occasionally, we intersperse examples from other areas, where we wish to emphasize a

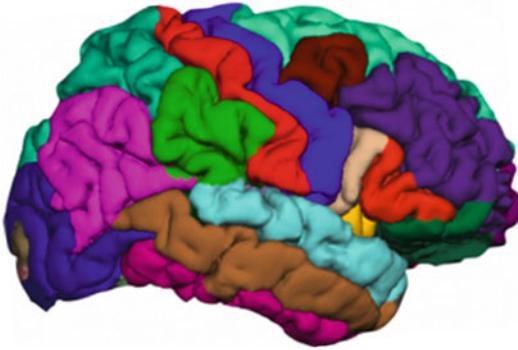


Fig. 20.3 Shows an example of a detailed segmentation of the brain into various anatomic structures by the FreeSurfer (<http://surfer.nmr.mgh.harvard.edu/>) package. It uses a combination of image intensities and expected shapes for the brain and substructures to produce its output

particular point, and imaging for educational purposes is discussed at length in Chap. 23.

The primary function of a Radiology department is the acquisition and analysis of medical images but also increasingly, the conduct of minimally invasive image-guided procedures. Through imaging, health care personnel obtain information that can help them to establish diagnoses, to plan or administer therapy, and to follow the courses of diseases or therapies.

Diagnostic studies in the Radiology department are typically performed at the request of referring clinicians, who then use the information for subsequent decision-making. The Radiology department produces the images, and the radiologist provides the primary analysis and interpretation of the radiologic findings. Thus, radiologists play a direct role in clinical problem-solving and in diagnostic-work-up planning. **Interventional radiology** and image-guided surgery (if done by the radiologist) are activities in which the radiologist plays a primary role in treatment.

The radiologic process (Greenes 1989) is characterized by seven kinds of tasks, each of

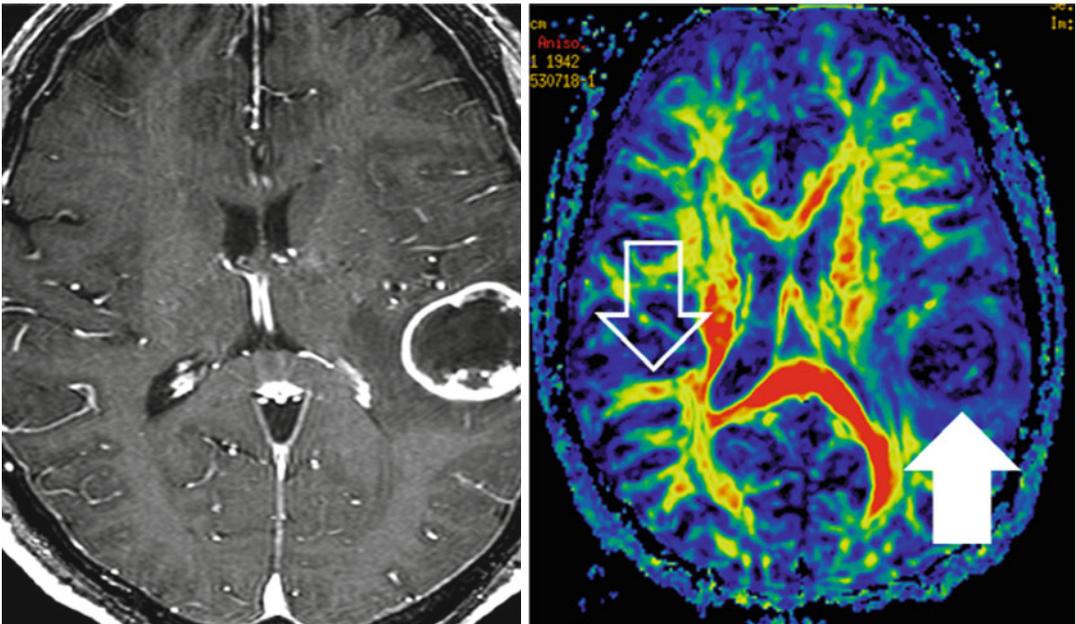
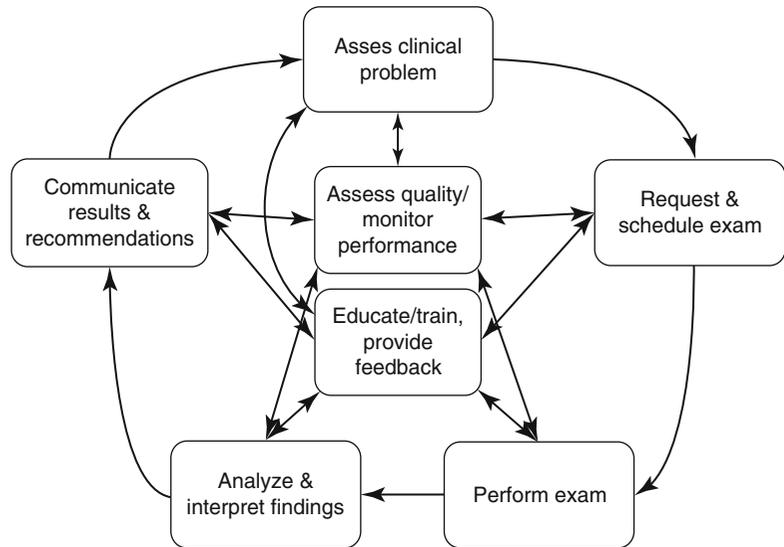


Fig. 20.4 Provides an example of diffusion tractography in a patient with a high grade brain tumor. In this case, one can see the replacement of the normal tracts (*open arrow*) with lack of tract signal in the region of the tumor suggest-

ing they are involved with tumor. *Closed arrow* points to a brain tumor which has displaced or replaced the normal white matter tracts

Fig. 20.5 The radiologic interpretation process



which involves information exchange and which can be augmented and enhanced by information technology, as illustrated in Fig. 20.5. The first five tasks occur in sequence, whereas the final two are ongoing and support the other five.

1. The process begins with an evaluation by a clinician of a clinical problem and determination of the need for an imaging procedure. Decision support tools (Chap. 22) are commonly used to help determine if, and what type of, testing should be performed.
2. The procedure is requested and scheduled, the indication for the procedure is stated, and relevant clinical history is made available.
3. The imaging procedure is carried out, and images are acquired. The procedure may be tailored for particular clinical questions or patient status considerations.
4. The radiologist reviews the images in the context of the clinical history and questions to be answered and may manipulate the images. This task actually involves inter-related subtasks: (a) detection of the relevant findings and (b) interpretation of those findings in terms of clinical meaning and significance.
5. The radiologist creates a report and may also directly communicate the results to the referring clinician, as well as making suggestions for further evaluation as needed. The anno-

tation and markup of images can be very helpful in communicating locations of findings, and serves as helpful landmarks for subsequent exams and for surgical or radiation procedures.

6. Quality control and monitoring are carried out, with the aim of improving the foregoing processes. Factors such as patient waiting times, workloads, numbers of exposures obtained per procedure, quality of images, radiation dose, yields of procedures, and incidence of complications are measured and adjusted.
7. Continuing education and training are carried out through a variety of methods, including access to atlases, review materials, teaching-file cases, and feedback of subsequently confirmed diagnoses to interpreting radiologists.

All these tasks are now, in a growing number of departments, computer-assisted, and most of them involve images in some way. In fact, radiology is one branch of medicine in which even the basic data are usually produced by computers and stored directly in computer memory. Radiology has also contributed strongly to advances in computer-aided instruction (see Chap. 23), in technology assessment (see Chap. 11), and in clinical decision support (see Chap. 22). Speech recognition is commonly used for report creation.

20.2.2 Electronic Imaging Systems

20.2.2.1 Image Acquisition

The first radiographs used an integrated detection, recording and display system—that is, the glass plate (and later, film) served both to detect the photons and to record them in a permanent form (after being ‘developed’) and also to display the data. This integrated arrangement survived for about a century. Today, most radiographs are either (a) recorded in a latent form (i.e., they are not directly visible, such as an electronic signal on a charged plate) and a ‘reader’ scans the plate to create a digital image (known as **computed radiography** or CR) or (b) the photons are directly converted to digital images (known as **digital radiography** or DR). The digital image can then be transmitted and stored like any digital data, using conventional networks and storage systems. They are displayed using conventional display systems. The matrix size of the images is variable, ranging from as low as 64×64 for some nuclear medicine images, up to $5,000 \times 4,000$ picture elements (pixels) for mammograms. The size of typical radiology images and examinations is shown in Table 20.1.

20.2.2.2 DICOM

The first medical devices to produce digital images routinely were CT scanners, and soon after, MRI scanners. The availability of digital data that represented a three-dimensional image stimulated the field of medical image processing,

which had been a relatively quiescent, largely research endeavor until then. But an early challenge to such investigations was that the medical device vendors supported the then-common half-inch tape media, but each vendor (and usually model of scanner) had its own format. Such formats were considered proprietary, and required each investigator to reverse engineer the format of the tape just to gain access to the data. Although computer networks were used in hospitals at that time, few if any scanners supported network connections.

The need to write all data to tape, and then read it into a computer using software unique to each scanner resulted in significant unnecessary effort. The need to exchange images efficiently demanded that they be represented in a standard fashion. This need was recognized by the American College of Radiology (ACR) and the National Electrical Manufacturer’s Association (NEMA), and led to the development of the ACR/NEMA standard for medical images in 1985. As other imaging devices started to produce digital images, and as the information about the images became richer, the second version was published in 1989. That standard described both standardized representations of the data, and prescribed a special connector for transferring image data between devices. This was demonstrated at the 1990 Radiological Society of North America (RSNA) conference. Soon after, **TCP/IP** became a widely accepted network standard, and while the ACR/NEMA standard did not describe a

Table 20.1 Typical sizes for radiology examinations

Modality	Image size (pixels/image)	Images/exam	Exam size (MB)
CR/DR	5,000,000	3	29
CT	262,144	500	250
MRI	65,536	500	63
US	262,144	50	25
Mammography	20,000,000	4	153
Interventional/Fluoro	1,048,576	50	100
Nuclear Medicine	16,384	25	1

CR computer radiography, DR digital radiography, CT computed tomography, MRI magnetic resonance imaging, US ultrasound

Note that there is variability in image size and images per examination, and these numbers should be viewed as very rough estimates. Furthermore, there is a strong trend for both increased image resolution (increasing image size) and more images per examination since the emergence of digital imaging

method for transferring data over TCP/IP, investigators fairly quickly implemented this, and it worked well. Continued improvements in the information model, as well as extension to medical specialties other than radiology, and standards for storage on physical media like optical disks demanded further revisions. The addition of non-radiology images also demanded a name change, and thus 'ACR/NEMA 3.0' was rebranded as **DICOM**, which stands for Digital Image Communications in Medicine.

The major adoption of DICOM by all image equipment providers was not until 1992–94. In 1992, the RSNA commissioned the creation of **Central Test Node (CTN)** software, for demonstrating the standard over a local area network in the **infoRAD** section of RSNA '92, followed by increasingly sophisticated versions over the next 2 years. The RSNA then made it available for free public access as a model for understanding the standard and design of utilities and tools by developers. During those years, the RSNA annual meetings hosted a major digital image interoperability demonstration that became progressively more sophisticated and demanding. RSNA and its meetings accordingly facilitated demonstration of the interconnection of vendor products through the Internet, promoted DICOM compatibility as a feature that could be visualized at participating vendor exhibits, and created a model **RFP** for radiology practices and hospitals to use to craft a DICOM requirement as part of the procurement of imaging systems. These efforts turned out to be extremely successful in transforming the marketplace from one that was dominated by proprietary formats to one that was standards-based and interoperable.

DICOM continues to be updated and improved through an international committee process. While it is hard for any standard to be both widely accepted and perfectly up-to-date, the DICOM governance has done a remarkable job of adapting to rapid changes. The governance continues to reflect its roots of combining industry and medical experts who are interested in providing the best technology that can be put into commercial products.

20.2.2.3 Image Transmission, Storage, and Display

Digital imaging provides the opportunity to store the images in digital form. In the early days, the size of the images represented a challenge—the amount of data was quite large relative to the capacity of storage devices. As a consequence, there was intense interest in using compression methods that could reduce the amount of storage that was required—as well as increase the speed of network transmission of images. Even with compression, the amount of storage used for images is quite large relative to non-image data stored in a hospital. A hospital must therefore carefully consider how images are stored. In the early days of **Picture Archive and Communications Systems (PACS)**, there was little choice, because the storage system was tightly integrated with the display and transmission. This was done because the high demands on storage, transmission, and display all required special hardware. As computer technology caught up, there was less need for specialized versions of networks, archives, and displays.

Early PACS utilized proprietary networking methods or other uncommon, even if standard, networks suited to high volume transmission. An example of the former is the PACS developed by LORAL, which leveraged technology developed for its defense applications. Its network was a hybrid of 10 Mbps **Ethernet**, which provided control signaling, and a unidirectional star configuration optical network that had lossless compression built into the network card. The optical network signaled at 100 Mbps, and because it was unidirectional, it routinely realized its theoretical speed. This speed was required to meet a design demand that any image be visible on the display screen within 2 s of the request. Even today, few PACS are able to meet this specification. Other vendors utilized **FDDI**, which also was an optical network that signaled at 100 Mbps. However, its handling of contention was much less effective, and its performance suffered. Today, standard Ethernet signaling at either 100 Mbps or 1 Gbps can provide adequate performance, as long as reasonable attention is paid to network layout and implementation.

The next part of the PACS concept to begin to separate was the archive. In the early PACS, updating the system to take advantage of new workstation or network technology meant that the whole archive needed to be updated or migrated. Because the data were not stored in a standard format, it was necessary to get the cooperation of the vendor to migrate the data to the new system. Because workstations rapidly change, but archive contents do not, there was perceived value in separating these two functions (Erickson and Hangiandreou 1998). Today, there are a number of vendors that sell 'vendor-neutral archives' which leverage the DICOM standard to allow a wide variety of image-producing and image-consuming systems to access the archive in a standard fashion.

Because the image datasets are quite large, there is interest in finding ways to reduce storage requirements. Image compression does exactly this, in one of two ways. There are **lossless compression** methods, which encode redundancy in the image in a way that allows the original to be *exactly* reproduced. **Lossy** (or irreversible) **compression** produces an image that is similar to the original. Exactly how similar depends on the algorithm and user-selectable settings that reflect the trade-off between fidelity and compression ratio (the ratio of original size to compressed size). The major challenge is that one cannot select a given setting, reliably get images that are not visibly altered, and also achieve a good compression ratio. While lossless compression methods can only get about 2.5:1 reductions in size, lossy compression can gain as much as 40:1 without a perceptible or diagnostic loss, *for certain types of images*. While the size of image examinations continues to increase, the decrease in storage cost is more rapid, lessening the demand for lossy compression. The use of lossy compression is more widely accepted in non-radiology specialties, such as cardiology and pathology, in part because of the greater uniformity of image characteristics, allowing easy specification of acceptable methods. A key goal of lossy compression is that it not have an adverse impact on diagnostic value to the human or to computer aided diagnostic algorithms at

routinely applied compression levels (Zheng et al. 2000). Thus lossy methods are usually tuned to the diagnostic task at hand so as not to have adverse impacts.

Early PACS also required specialized display devices. At the time, standard computer displays were as high as 640×480, but commonly less. Images were more than 2,048 pixels in each direction. Liquid crystal technology for large displays was also not developed, meaning that the displays were large cathode ray tubes. These displays were large, heavy, produced much heat, and degraded rather rapidly. Nearly all were monochrome. Imaging also required a higher luminance for detection of subtle gray level distinctions than was possible with consumer-oriented displays, even more so with the focus in consumer devices on color displays which often did not have a bright white background. Expensive displays were accordingly needed to provide both the high resolution and high luminance. Today, flat panel technology that meets the demands of most radiological images is widely available. Some have advocated the use of consumer-grade displays (Hirschorn and Dreyer 2006), though the more common practice is to use medical grade devices (Langer et al. 2006). Another work of the DICOM committees was the establishment of display requirements for medical purposes—requirements that the device be able to show enough unique levels of gray to enable diagnosis, and that the scale be perceptually linear (ACR-NEMA 2006). Computer values sent to the display may range from 0 to 255 in intensity. However, the difference in perceived intensity when digital values change from 0 to 10 is not the same as the perceived intensity change when the digital values change from 100 to 110. That is because the eye's sensitivity to photons does not match the change in the number of photons produced by a display at different intensity levels, i.e., the eye's sensitivity to photons has a nonlinear response curve. Since this non-linear response is fairly consistent between humans, it is possible to adjust the digital values to create a perceptually linear display, which should be optimal for the human perceptual system.

20.2.3 Integration with Other Health Care Information

20.2.3.1 Radiology Information Systems (RIS)

A **Radiology Information System**, or RIS, is responsible for much of the textual information in a radiology department. There are some core functions that all RISs must be able to perform, including the capture of the interpretation for a given examination, and the recording of the status of an imaging examination. Most RISs also do more, depending on what other systems are available and preferred for a given situation. Most examinations must be ordered (there may be exceptions in cases like an emergency department). Once ordered, the examination must be scheduled—the time and imaging device must be known and coordinated with the schedule of the patient, and inclusion of patient demographics. These functions may be performed by the hospital information system (HIS) or electronic health record (EHR) system. Similarly, the report must be provided to the ordering physician, and a bill must be issued. These functions may also be provided by the HIS or EHR system, but must be provided by the RIS in cases where there is no HIS or EHR (such as many outpatient imaging centers). Early RISs needed to provide a mechanism for entering reports, usually by a transcriptionist typing into the RIS. Once transcribed, the RIS would usually also provide a way for the radiologist to review the transcription to assure it was correct, and then electronically sign it, at which time the examination was considered final. In cases where the transcription occurred substantially after the dictation, some RISs provided a mechanism to access the audio file. At institutions with residents or fellows, the RIS would usually also provide a preliminary interpretation provided by the resident/fellow, but before the staff person approved the report as final.

20.2.3.2 Speech Recognition

We noted that the RIS previously would provide a means for a transcriptionist to type the text of the report into the RIS. Today, the vast majority of radiologists use speech recognition to convert

their speech into text. In some cases the text is immediately reviewed by the radiologist and approved as final. This model has the advantages of rapid **turn-around time**—the time from the examination being ready to be reported to the time it has a final report available. In this model, a separate application (the speech recognition system) converts the audio to an HL-7 message, which is sent to the RIS along with the final (or other appropriate status). In other cases, a ‘correctionist’ reviews the text created by the speech recognition system, and corrects it based on listening to the audio file. In this case, the radiologist must then review the text again to make it final.

There are two major advantages to using speech recognition: First, it enables rapid turn-around time. Before speech recognition, turn-around times of 1 week were common, but now, turn-around times of less than 2 h are common (Hart et al. 2010; Krishnaral et al. 2010; Mattern et al. 1999). This improvement in turn-around time undoubtedly improves the quality of care provided to patients. Second, it reduces staffing for radiology departments or hospitals by eliminating or reducing the number of transcriptionists/correctionists needed. Of course, some decrease in productivity is commonly observed for radiologists, which reduces the economic benefit (Langer 2002; Strahan and Schneider-Kolsky 2010).

Over the years, there have been multiple research efforts aimed at enabling radiologists to generate structured reports from selection of choices in forms, and through use of drop-down menus, macros that produce predetermined text phrases, and other techniques. Some of these are now used in specific situations, especially where reports have a largely anticipated format and structure, e.g., mammography and obstetrical ultrasound, and macros are used in conjunction with speech recognition approaches for certain “canned” sections or reports. However, there is not yet widespread adoption of structured reporting in radiology.

20.2.3.3 Computer-Aided Diagnosis (CAD)

The interpretation task consists of detection, description, and diagnosis. In some cases, the detection task can be quite challenging, particularly

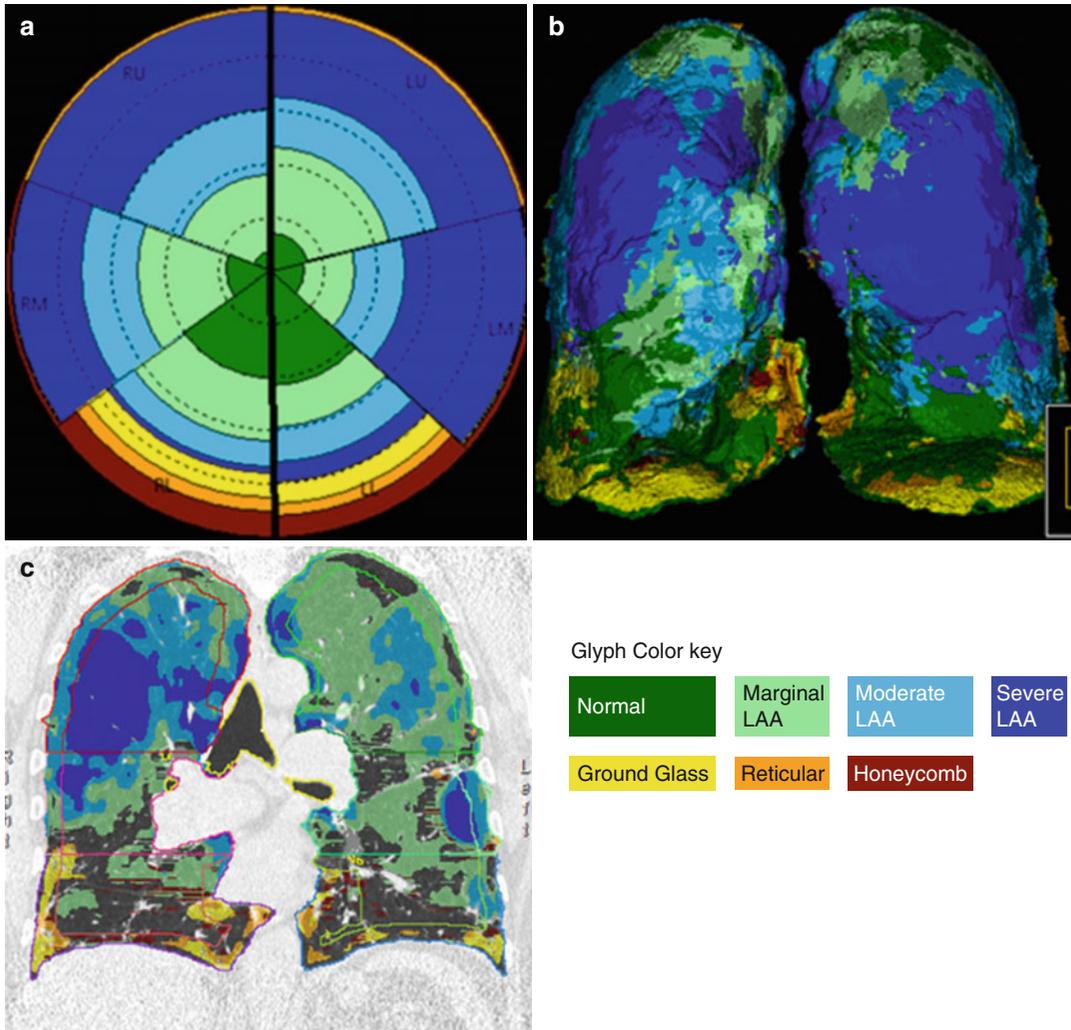


Fig. 20.6 (a–c) shows the output of the experimental algorithm CALIPER, rendered as a 3D image, to show the distribution and change of different degrees of interstitial lung disease in a patient (Courtesy Brian J. Bartholmai, MD)

for screening tasks involving mammography and chest X-rays because the incidence is rather low, and the volume is high. Particularly at the end of a long shift, human observers probably have decreased performance due to fatigue. For these cases, computer algorithms that highlight suspicious regions of an image may be useful to assure that important findings aren't missed. Some have called this role 'computer-aided diligence'.

In most studies of the value of **computer-aided diagnosis (CAD)**, the value is either minimal, or provides benefit mostly to non-expert readers (Gur and Sumkin 2006). It is not clear that

CAD adds value for radiologists that subspecialize in the body part being imaged (e.g., mammographers do not benefit from current CAD algorithms for mammograms). However, just as it was unimaginable that a computer could beat the best chess players in the early days, it is likely that over time, CAD will become better than humans.

Another role for CAD is in assisting with diagnosis. This has been most commonly used for high resolution CT images of the chest with findings of interstitial lung disease, though it has been described for other findings, including mammography (Elter and Horsch 2009). The

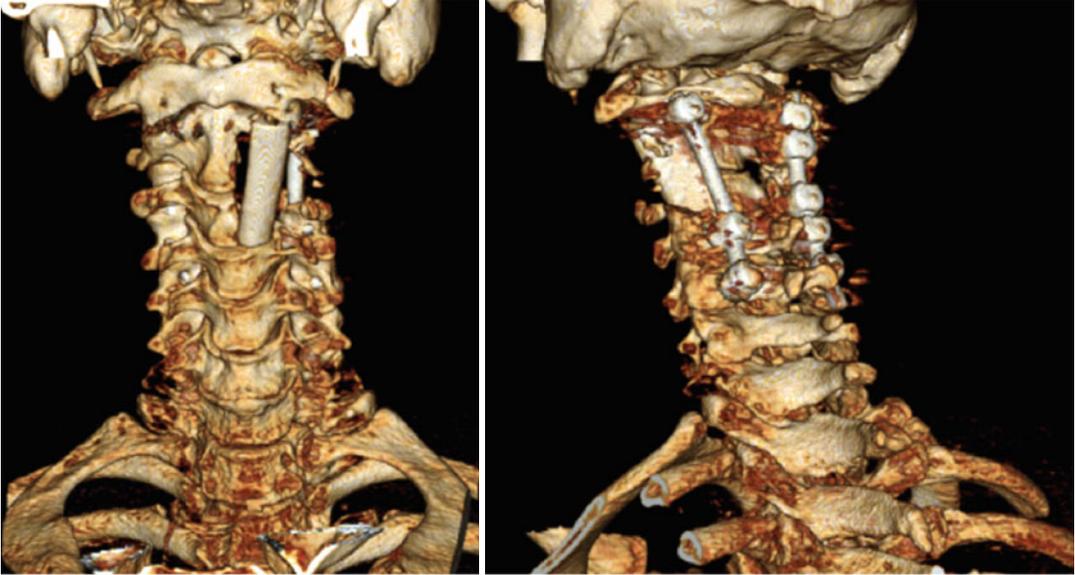


Fig. 20.7 Provides an example advanced visualization of the cervical spine after resection of a tumor, distributed via a web client. This allows the surgeon to review findings and discuss them in their own office

CAD algorithm can assist in differentiating the various types of lung disease. Again, this is probably most useful to radiologists who do not do a large volume of lung imaging, and may have less experience with various interstitial lung diseases and their appearance. Figure 20.6 shows an image of the output of the experimental algorithm CALIPER, rendered as a 3D image, to show the distribution and change of different degrees of interstitial lung disease in a patient.

20.2.3.4 Advanced Visualization

CT and MR scanners provide images that can be thought of as 3D images, even if they are not always truly acquired as 3D, but rather, as a series (or stack) of 2D images. In fact, some imaging devices can acquire a series of 3D images through time, thus representing a 4D image (time becomes the fourth dimension in these cases). In particular, cardiac imaging benefits from 4D capability so that the beating heart can be examined throughout the cardiac cycle. Such data sets are quite large, and proper demonstration of the important findings requires visualization of the data as specially processed images. For instance, if one wishes to see a skeletal finding using CT, one can set a threshold to select bony structures, and then

render it using traditional computer rendering methods. This can be done on multiple time points to produce movies of moving structures.

The great challenge in medical visualization is **segmentation**—deciding whether a volume element (voxel) is a part of the structure of interest or not. In the case of a CT image of bone, segmentation is quite easy. If intravascular contrast is administered during the examination, that can make it fairly straightforward to select vessels (arteries and/or veins depending on the timing). Soft tissue organs like livers, kidneys, and muscles are more challenging, but very feasible. A description of the rendering algorithms and their trade-offs is provided in Chap. 9.

A recent advance in visualization tools is to have the computation done on a central server, with interactive segmentation and rendering capability available via web browsers. This provides access to a much larger population of physicians, and can be valuable for surgeons contemplating surgery, as well as for patient education. Figure 20.7 provides an example advanced visualization of the spine, distributed via a web client, which allows surgeons to better plan and review treatment options in their own office, with the patient.

20.2.3.5 Advanced Reporting

While textual reports have served medical practice fairly well for the past century, there are opportunities to improve reporting. Multimedia reports provide a richer representation of the information present in the examination, and might include links from portions of the text report to specific images and locations on the images, moving images ('video'), or audio files such as the heart sounds. In some diseases, it can be important to have specific measurements made, and possibly tracked over time. If these measurements are encoded in a specific way, it will be easier to extract and use that information elsewhere in the medical record, and for other purposes like research. **Lexicons**, such as RadLex, can be helpful in conveying some of the information. There is great interest in routinely collecting more quantitative information from images, because it appears that for an increasing number of diseases, quantitation is receiving increased attention in clinical realms.

A structured report is produced when all of the concepts are represented using coded terminology. There is a DICOM specification for structured reporting, though adoption has been poor as noted in Chap. 9. This is because there are currently not efficient user interfaces for creation of structured reports in most areas of radiology. The best example of structured reporting is the use of BIRADS in breast imaging. Because the possible disease findings are limited in mammography, the list of anatomic structures and associated pathologies are limited. BIRADS assumes the organ of interest is the breast, and offers a targeted coding system for the type of lesion that is seen and the recommended clinical approach to that lesion.

20.2.3.6 Workflow Management (Including Dashboards)

The ability to monitor and control events in an imaging department is critical to efficient and effective operation. **Dashboards** have been applied in many business arenas as tools that give quick visual displays of **Key Performance Indicators (KPIs)** for a particular business. Such dashboard technology is now becoming widely used within imaging departments for monitoring

such KPIs as report turn-around time, patient waiting time, number of days out to schedule certain types of examinations, and revenue days-outstanding. The dashboards give people a quick view of what is happening, and can alert them to problem areas. Figure 20.8 is an example of a radiology dashboard that shows important departmental metrics, including report turn-around time, compliance with notification requirements, and patient waiting times.

Most dashboards provide a mechanism to 'drill down' on a particular problem area. For instance, if the patient waiting time monitor goes 'red', clicking on that indicator light could show the waiting time by location (maybe just one facility is causing the problem), total patient volume (maybe the site is experiencing a spike in patient volume), or examination time (maybe the complexity of examinations is going up). Such information is critical to enabling a timely and effective response to sub-par performance.

20.2.3.7 Teleradiology

Teleradiology is the practice of interpreting images at a location that is physically distant from the place where the images are collected. Initially, this referred to transmitting images from the hospital to the radiologist's home in the middle of the night so that the physician did not need to drive in to see the image onsite. While this is still done, it is now common for a hospital to contract with a 'nighthawk' service that will provide these nighttime interpretations. A nighthawk service contracts with many hospitals—enough to keep a team of radiologists busy during the night. Having a team continuously operating is usually more efficient, and allows for specialization of image interpretation. Teleradiology is now also practiced during the day to balance clinical workload and to provide specialized interpretation on a routine basis. The technology to rapidly transmit images across large distances is widely available and inexpensive. The greatest challenges to teleradiology are licensing/credentialing issues, especially if films are read across state lines or internationally (radiologists may be licensed to practice where they review the films but not in the location where the patients were located when the images were acquired).

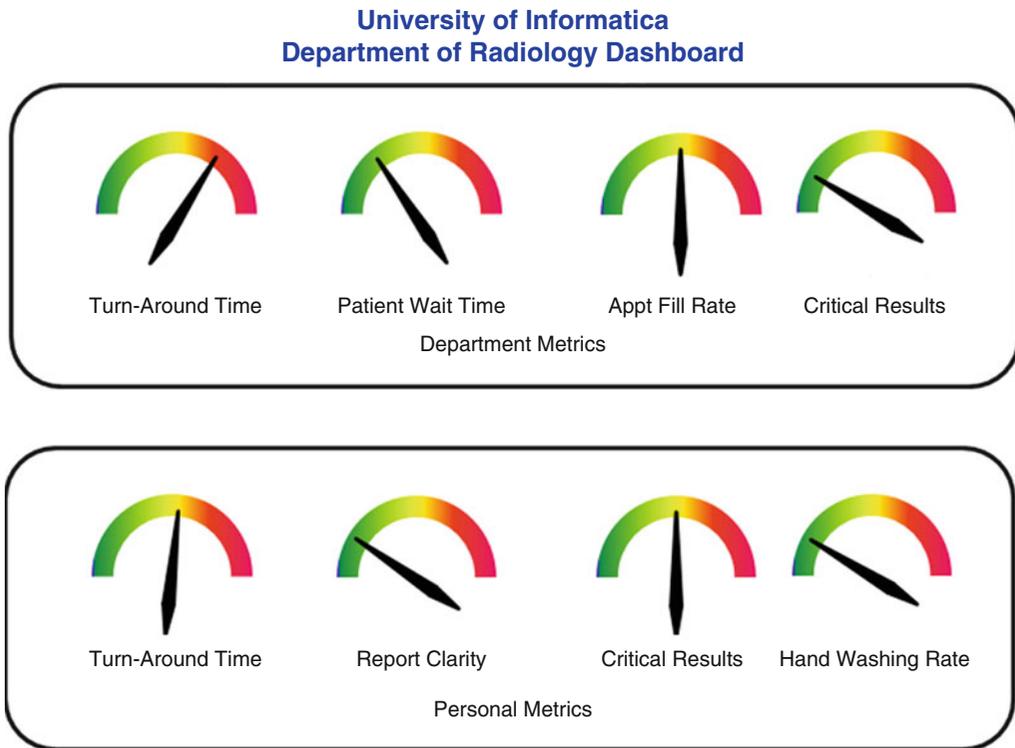


Fig. 20.8 is an example of a radiology dashboard that shows important departmental metrics, including report turn-around time, compliance with notification requirements, and patient waiting times

20.2.3.8 Enterprise Integration (Including HL7, CPOE)

Medicine is an information-rich business, and providing access to the relevant information in a timely fashion is critical to success. Integration of systems with the relevant pieces of information is necessary, and in hospitals is generally done with HL-7 messages (see Chap. 7). Referring physicians increasingly expect to view images and to see reports with rich information. HL-7 does not address these demands well. Similarly, many EHRs are not able to address these needs.

Because medical imaging has been a major component of increases in total health care costs, there has been much attention paid to assuring that only necessary examinations are performed. To help assure this, decision-support systems to guide proper ordering have been developed that have been shown to have an impact on utilization of imaging studies (Sistrom et al. 2009). Such systems have been shown to decrease the total

number of examinations performed, and in particular to decrease the number of examinations that appear to be unnecessary. In addition to alerting the user to a potentially improper order, educational materials are often provided to help the ordering physician understand when and what imaging examinations might be appropriate for the given indication. In addition, such systems can provide management reports to improve the understanding of ordering practices.

20.3 Imaging in Other Departments

20.3.1 Cardiology

Cardiac imaging has many similarities to radiological imaging, and in many cases is performed either by radiology departments or in conjunction with radiology. The primary imaging modalities for cardiology include echocardiography

(ultrasound), catheterization (interventional/vascular, involving fluoroscopy and angiography, i.e., vessel visualization via contrast dye administration), MR, CT, and PET. The workflow can be similar, but can be different in those cases where the imaging is performed by the same department and even by the same individual as the person who ordered it. In such cases, there can be less formal ordering, scheduling, and reporting. However, as the imaging is increasingly a part of the general enterprise, such informality will become a greater challenge.

Cardiology has been more aggressive in its use of lossy compression. This is primarily because the nature of cardiac imaging is much more stereotyped and there is less concern about fine resolution. There is primary focus on the heart, whereas in radiology many different organs with very different appearances can challenge compression methods. The echocardiographic and interventional images are also much more like video—usually being motion-oriented rather than focused on static capture. In fact, the major cardiovascular societies have published and supported the use of specific compression technologies and settings for cardiac imaging (Simon et al. 1994; ACC/ACR/NEMA Ad hoc Group 1995).

Because the focus is primarily on the heart and its function, cardiac imaging is more advanced in structured reporting. The primary variables that are of interest in cardiac imaging (left ventricular volumes, stroke volumes) are of interest in most cases, and are routinely measured. This has driven the acceptance of structured reporting for the common measurements in cardiac imaging—particularly echocardiography.

20.3.2 Obstetrics and Gynecology

Obstetrical and gynecological imaging is rather like cardiac imaging, except that it is much more focused on ultrasound. Much like cardiac imaging, there are a well-defined and accepted set of measurements and observations expected for the routine obstetric exam, and as such, structured reports for these findings are widely used.

Estimates of fetal gestational age and development are typically automatically assessed, on the basis of measurements using well-tested prediction models.

20.3.3 Intraoperative/Endoscopic Visible Light

It is increasingly common to capture still images and video of endoscopic procedures as well as traditional open surgical procedures. These images are valuable for documenting the important findings (or lack thereof) during a procedure. They are also useful for educational purposes, including informing the patient of the findings and procedures carried out. Some surgeons have suggested that medicolegal demands will require routine capture of entire surgical procedures.

Such images can be more graphic and revealing than radiological images, and in some cases have driven the expectation of need for an additional level of privacy protection. In one institution, for instance, all photographic images from the Plastic Surgery department are protected from access—only physician members of the Plastic Surgery department can routinely view those images, with a process for granting temporary access to other care providers (Erickson et al. 2007).

20.3.4 Pathology and Dermatology

Pathology and dermatology have similar needs, except that dermatology includes photographic visible light images of skin lesions. For these purposes, consumer-grade photographs can be sufficient, but transporting those images (usually in JPEG form) to a medical-grade imaging system will usually require an import process. This process will require confidence about the accuracy of patient and site location information. Often, the JPEG images are then ‘wrapped’ with DICOM information to assure that the connection between a photograph and a patient exists at the file level, rather than via a link to a filename. Image viewers require color capability, but

otherwise are not substantially different from what is provided in most radiological image viewers. If images are converted to DICOM, the archive system is usually able to store them without difficulty.

Microscopic images represent a bigger challenge. At this point, there are two strategies for the capture of microscope images: the first is **whole slide digitization** in which the entire specimen is digitized; the other is capture of specific views that are of interest. In both cases, though more so in whole-slide imaging, there is a need for multi-resolution viewing. That is because the workflow is very different. Whole-slide scanning is usually done *prior* to the pathologist reviewing the images, while the spot-capture is done by the pathologist at the time of viewing. In the former case, the computer performs the pan-zoom function, while in the latter case the optical microscope performs that function. In the former, the computer is a diagnostic device, while in the latter, it is used mostly for documentation purposes.

Whole-slide scanning is of greater interest, because it has greater possibilities for improving health care delivery by allowing the slides to go to the pathologist. It also represents a much greater challenge, because much larger amounts of data must be stored and the associated computer-based viewing application requires the ability to display low resolution and high resolution images. Computing low resolution images from high resolution images can be computationally expensive. Instead, the DICOM standard uses compression methods that start with low-resolution representations, and builds high-resolution views from the lower-resolution images. As such, it is both computationally efficient and data storage-efficient.

Another important issue differentiating pathology imaging from radiological imaging is that retrieval of old images is uncommon in digital pathology. This would usually only occur when there is a medicolegal issue, or possibly in case of disease recurrence or metastasis, where there is a need to compare the older sample with a newer one.

20.4 Cross-Enterprise Imaging

20.4.1 CD Image Exchange

When images were stored on film, sharing images with another hospital required that the films be either physically transferred or copied. Copying a film was labor-intensive and expensive. Therefore, it was standard practice to ‘loan’ films to other facilities when needed.

With digital images, it is much easier to copy the digital data onto media like a compact disc (CD) and give that to the patient. There are well-accepted standards (DICOM) for how to store the images on a CD. However, it is challenging for most hospitals to use the images on CDs. In some cases, the images can be imported into the PACS, but that can cause confusion about where the study was done, and can be challenging for the RIS to represent this (who ordered the CD exam, and where the report is located). On the other hand, if one does not import the study into the local viewing environment, there may not be viewing applications for the images on physicians’ computers. Including the software for a viewer on the same CD means the physician must learn how to use that viewer if they are not already familiar with it.

In addition, there are important data integrity issues—as much as 0.1 % of CDs have been shown to include images for patients other than the intended patient (Erickson 2011), leading to important health delivery and legal risks.

20.4.2 Direct Network Image Exchange

The problems with CD image exchange noted above, as well as the time delays and costs, have driven many institutions to use internet transfer mechanisms. In cases where there is a high volume and a high level of trust, one can establish **virtual private networks (VPNs)** that allow secure transfer between two institutions. While this allows rapid and low-cost transfer, it still requires confident patient identification, and a method for importing the images into some form of clinical viewer.

For less frequent/ad hoc transfers, setting up a VPN is not practical. There is an attempt currently underway to leverage **Personal Health Records (PHRs)** (see Chap. 17) to allow transfer of images (RSNA 2009). This system ‘gives’ the images to a patient-controlled online health record. By giving it to the patient, issues of security and HIPAA are significantly reduced. Still, although the problem of how a ‘receiving’ institution will view or import the images from the patient need to be addressed, this option appears appealing. The major challenge to this model is lack of widespread adoption (see the health record bank discussion in Chap. 13).

20.5 Future Directions for Imaging Systems

The increasing capabilities of mobile devices and the increasing expectations of ready access to medical professionals have driven imaging onto mobile devices. At present, the FDA has limited the use of such devices for diagnosis. On the other hand, these devices can be extremely useful for consultation on specific areas of an image, or when therapeutic options are being considered, or for patient communication. As the bandwidth and display qualities improve, these devices will likely play an increasing role in both diagnosis and therapy planning.

Cloud technology (see Chap. 5) is also looming as an important technology in the future of medical imaging. The ability to leverage efficiencies of scale is an important economic driver that is pushing many smaller imaging providers to use cloud-based storage. Perhaps a greater medical need driving the use of cloud is the widespread access that cloud technology provides. As more images are transferred to cloud storage, we expect that greater computational capabilities in the cloud may drive more computer aided diagnosis and advanced visualization to cloud providers.

Phenome characterization (see Chap. 25) is becoming an important aspect of the move to individualizing medicine sometimes referred to as ‘**precision medicine**’. Data contributing to phenome characterization can certainly come from reports of imaging procedures, but it may

also be true that image features themselves, e.g., parameters describing nodules or tissue characteristics, may contribute to this knowledge base. This will become especially true as advanced imaging methods such as specialized MRI techniques and imaging at the cellular level are used for biomarker characterization.

Suggested Readings

- Branstetter, B. F. (2009). *Practical imaging informatics*. New York: Springer. As its title implies, this book is a practice-oriented book primarily aimed at those responsible for implementing and maintaining a digital imaging practice. The format of the book is an outline with many practical tips from a wide variety of experts.
- Dreyer, K. J. (2006). *PACS: A guide to the digital revolution*. New York: Springer. This is also a book focused on the practical aspects of implementing and maintaining a digital imaging department. Its format is that of a traditional textbook, and covers a broad range of topics.
- Geoff, D. (2009). *Digital image processing for medical applications*. Cambridge/New York: Cambridge University Press. This is an excellent, practical book on concepts of image processing algorithms used in medical imaging. ISBN 978-0521860857.
- Liu, Y., & Jihong, W. (2011). *PACS and digital medicine*. Boca Raton: CRC Press. This book goes into greater detail of the technology of PACS, and to a lesser degree RIS and EMR. This is a very good resource for those interested in more details of DICOM and how a PACS can be configured to address specific needs.
- Wolfgang, B. 2010. *Applied medical image processing: A basic course*. CRC Press. As the title says, this is an introductory book, with many excellent explanations and example code (mostly MatLab). ISBN 978-1439824443.

Questions for Discussion

1. What are the Pros and Cons of a highly structured technology like DICOM? DICOM has been highly successful in terms of adoption as a standard, and virtually all image communication utilizes it. This differs markedly from some other standards. What are factors that have contributed to this success, and what lessons can be drawn from this in terms of how to promote adoption of standards in the future?

2. If one were to design medical imaging systems today, would the optimal design continue to have PACS and RIS as separate systems, or would they be combined into one system? Should these be separate from the EHR?
3. What are the ways in which radiology reports of examination interpretations can be generated, and what are the advantages and disadvantages of each approach, in terms of ease and efficiency of report creation, timeliness of availability of report to clinicians, usefulness for retrieval of cases for research and education?
4. In these days of high bandwidth and low storage costs, is there still a good reason to use lossy compression in medical

imaging? What kinds of trends are likely to affect image growth, as part of the patient's medical record?

5. What are the arguments for maintaining raw rather than compressed data (not only for imaging data but for compression or summarization of other types of data)?
6. Describe a classification of ways in which image data are used in medical decision making.
7. What are the data management implications of using a separate advanced visualization system for clinicians that is distinct from the PACS used by radiologists for interpretations? What if the radiologists use that system in addition to the PACS?